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Glacial erosion in the Scottish highlands

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steam-yacht *Scotia*. Another Edinburgh firm of old renown in connection with geography, Messrs W. and A. K. Johnston, have presented copies of their Royal Atlas, M.P. Atlas, and Commercial Atlas, as well as eleven wall-maps of physical geography. Messrs. Longmans have presented a copy of their *Gazetteer of the World* and one of the latest edition of the lecturer's *Handbook of Commercial Geography*. Messrs. Macmillan and Co. have presented copies of their more important publications connected with the teaching of geography, including *The International Geography*, edited by Dr. H. R. Mill, as well as a copy of their new Orographical Map of Europe, prepared under the direction of Mr. A. W. Andrews and Mr. B. B. Dickinson. The Oxford University Press has presented the complete series entitled *The Regions of the World* (six volumes), edited by Mr. H. J. Mackinder. Messrs. George Philip and Son have presented a copy of their *Mercantile Marine Atlas of the World*; and finally, Mr. Stanford has presented the entire series of seven Orographical School Wall-maps prepared under the direction of Mr. H. J. Mackinder. All these donors I have to ask to accept my hearty thanks in the name of the department. Thanks are also due and are hereby cordially tendered to Mr. David Hay Peffers of Belhaven, Dunbar, who has spontaneously offered to lend gratis to the department at any time when it may be of service old maps from the interesting collection which he has formed and of which some specimens are now shown on one of the walls.

GLACIAL EROSION IN THE SCOTTISH HIGHLANDS.

By Professor RALPH S. TARR of Cornell University.

(With Illustrations.)

Introductory.—Having two weeks of leisure time in the summer of 1907, I decided to spend it in the Highlands of Scotland, primarily for the purpose of seeing how far the topography of that region gave evidence of powerful glacial erosion; and how it compared with other glaciated regions in these respects. As I expected, the phenomena of the Alps, of Norway, of Central New York, of Greenland, of Alaska, and of other glaciated regions, were duplicated here. Having studied the subject of glacial erosion in some detail in various regions of former and present glaciation,¹ it may not be deemed presumptuous on my part if, even though an outsider, and notwithstanding the shortness of my stay, I make a brief statement of the phenomena of glacial erosion in the Highlands as I saw and interpreted them.²

¹ In the Alps, the State of New York in the United States, Greenland, and Alaska.

² By boat, by rail, by carriage, and on foot I went from Glasgow up Loch Lomond, thence to Lochs Katrine, Ericht, and Rannoch, with some side excursions and walks across country. I then went up the west coast as far as Kyle of Lochalsh with excursions into several of the coastal lochs. Thence by rail I went to Inverness westward by steamer along Lochs Ness, Oich, Lochy and Eil, and after a few short trips round about Ben Nevis, back to Glasgow by rail.

SOME ELEMENTARY PRINCIPLES.

Normal Relation of Tributary and Main Streams.—As that eminent Scotsman, Playfair, so clearly stated over a century ago, "Every river appears to consist of a main trunk, fed from a variety of branches, each running in a valley proportioned to its size, and all of them together forming a system of valleys communicating with one another, and having such a nice adjustment of their declivities that none of them join the principal valley, either on too high or too low a level; a circumstance which would be infinitely improbable, if each of these valleys were not the work of the stream that flows in it."¹ The work of a century has not modified this law, which may be accepted as a fundamental principle of physiography.

Wherever one studies valley relations in regions of non-glaciation, the operation of this law is clearly seen. So great a river as the Colorado of western United States, rapidly cutting its way into the strata 6000 feet below the plateau top, has not been able to leave its weak tributaries behind even though they are dry for the greater-part of the year. They enter the main stream through valleys at an accordant grade. It is true that there are exceptional cases where a main stream in non-glaciated regions has worked so much more effectively that the side-streams enter through valleys that are out of accord—hanging above the main-stream bottom. Such cases are not only exceptional, but in all cases so far studied they are easily explained as the result of unusual conditions. They are, in other words, abnormal.

Relation of Tributary and Main Streams in Glaciated Regions.—In regions of glaciation, on the other hand, discordance of tributary to main stream is found on every hand; and in places of most vigorous glacial action it becomes almost the rule, thus apparently, in those regions, opposing the Hutton-Playfair law.

Take the case of Alaska, for example.² For a thousand miles along the Inside Passage to Alaska one sees instance after instance, numbering hundreds in all, where the tributary valleys join the main valleys at discordant levels, entering them all the way from one or two hundred feet to a thousand feet and more above the main-valley bottom. (See Figs. 1 and 2.) The hanging tributary valley here becomes almost the rule. The same is true in the multitude of branch fiords of this coast. In Yakutat Bay, for instance, the field of my own special studies in Alaska, broadly open tributary valleys breach the walls of the main valleys hundreds of feet above the main valley, perched or hanging there in a most remarkable position (see Fig. 3.) In this region I specifically applied all conceivable alternate explanations, such as differences of rock structure, faulting and others, in each case finding the hypothesis untenable. Only one hypothesis, that of glacial erosion,

¹ Playfair, *Illustrations of the Huttonian Theory*, 1802, p. 10.

² See G. K. Gilbert, *Harriman Alaska Expedition*, vol. iii. 1904, pp. 114-119, 139-161, and R. S. Tarr, "Glacial Erosion in Alaska," *Popular Science Monthly*, vol. lxx. 1907, pp. 99-119.

deepening the main valleys in excess of the laterals, is capable of explaining the facts seen there.

If one grants the possibility of glacial erosion operating more powerfully along lines of free flow than others, then the hanging valley is a necessary result. It follows as certainly as accordance of grade does in river work, as Playfair states the law. In view of the fact that hanging valleys would be a normal result of glacial erosion, if one admits the possibility of glacial erosion, it is certainly a fact worthy of consideration

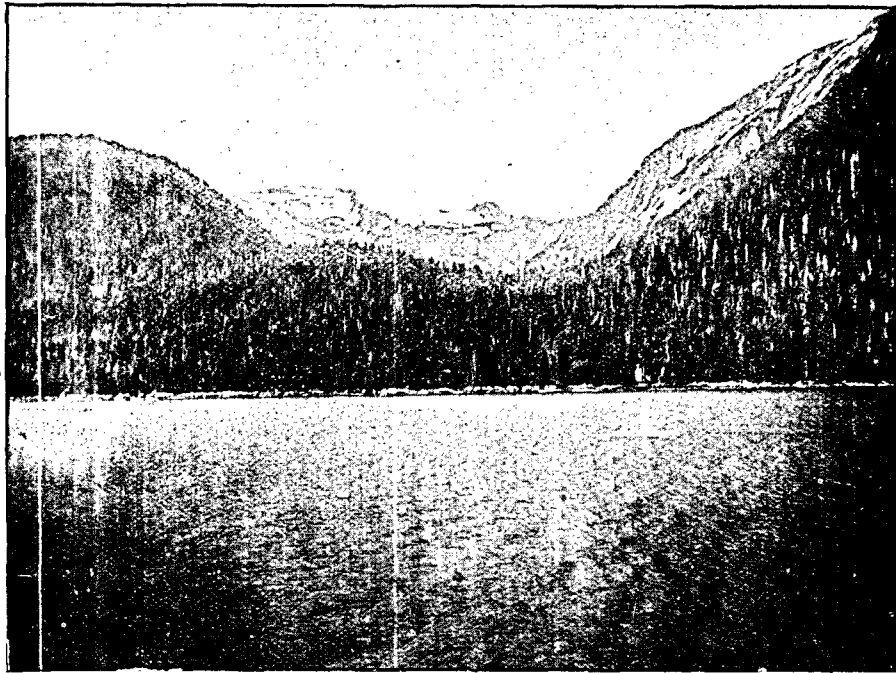


FIG. 1.—A hanging valley. Inside Passage to Alaska. To the right of the illustration a white spot marks the waterfall of the stream that flows out of the broad U-shaped valley.

that such valleys are practically confined to regions of present and former glaciation.

Most students of glacial action are now convinced that there has been profound glacial erosion in favourable places, though some still oppose this view. Those who have seen in the peculiar topography of glaciated lands clear evidence of powerful glacial erosion, have had much the same task in convincing others that Hutton and Playfair had in establishing the simple (as we now see it) principle of valley formation by river work.

Other peculiar Topographic Features in Glaciated Regions.—Glacial striations, grooves and gorges, like hanging valleys, are confined (unless we include such phenomena as iceberg grooves) to regions formerly

glaciated. Less generally recognised is the evidence of plucking, especially clearly seen in regions of crystalline rocks, like the Scottish Highlands, where the cliffs and exposed ledges furnish definite evidence that the ice was working not merely as an agent of polishing and striation, but also in quarrying. Evidence of plucking is clear on both ends—(a) on the ledges, and (b) in the boulder-strewn fields where the unconsumed fragments were dumped. Fresh rock ledges, as contrasted with disintegrated and soil-covered rocks, are equally characteristic of regions of recent glaciation.

Smoothing of valley sides and the erasing of minor tributaries is another feature of glaciated lands, and it is often associated with a grooving of the valley sides, giving rise to a series of sub-parallel descending rock-terraces, sloping downward in the direction of ice motion. The erasing of minor tributaries is often so complete that the post-glacial streams of this class descend the valley walls in parallel courses almost flush with the valley slope—not yet having had time to trench the rock with even shallow gorges, and not having even begun to develop a dendritic arrangement of stream course by the coalescing of the close-set, independent streams. In parts of Alaska from which the glaciers have just receded, hundreds of parallel streams descend straight down the valley slope, often only a few feet apart, with no valleys of their own, and no tributaries; and their number increases after a rain. In Scotland, from which the ice has been gone so much longer, the same condition of drainage is present, though the larger streams have begun to cut gorges, and some of the smaller streams have joined the larger as tributaries, making a beginning of the normal dendritic drainage.

Where glacial erosion has been most active it has not only deepened the valleys but has broadened them. Normally a valley that a river is cutting is winding, with a series of rock spurs alternating, first on one side then on the other, and overlapping. One finds this condition almost anywhere that glaciers have not been. But in glaciated regions the overlapping spurs, as well as the minor tributaries, have in many places been partly or wholly erased. Sometimes it is only the tip of the spur that is gone, giving it a truncated appearance (Fig. 4); but in extreme cases the spurs for long distances are entirely gone. This gives rise to straight valleys, with smooth, steeply rising walls, and with hanging valleys in very perfect development. Some of the valleys of the Scottish lochs illustrate this condition admirably; and in Alaska it is so strikingly clear that the straight reaches of the Inside Passage are popularly called "canals." Where is river work giving rise to rock-walled valleys of the "canal" type?

Accompanying these phenomena is a steepening of the valley walls, so that there are two slopes—a lower one where glacial erosion was most active, and has erased much or all of the pre-glacial topography, and an upper one, more gentle, where glacial erosion has done little, and where the older topography has survived (Fig. 4). Sometimes the upper margin of this steepened lower slope is essentially coincident with the level of the hanging valleys; but not always, for the bottoms of the hanging valleys have themselves often suffered glacial erosion to a minor

degree. This is why the hanging valleys are not at uniform levels. Those that have been occupied by the largest and most freely moving glaciers have been lowered most; and thus it happens that the elevation at which two neighbouring valleys hang above the main-valley bottom may be widely different.

Still another peculiar topographic feature of glaciated regions is the presence of rounded knobs, sometimes in the centre of a valley, sometimes on its side. They exist as nunataks in valley glaciers, as islands in lakes, and as rock knobs in valleys. They are residuals left behind,

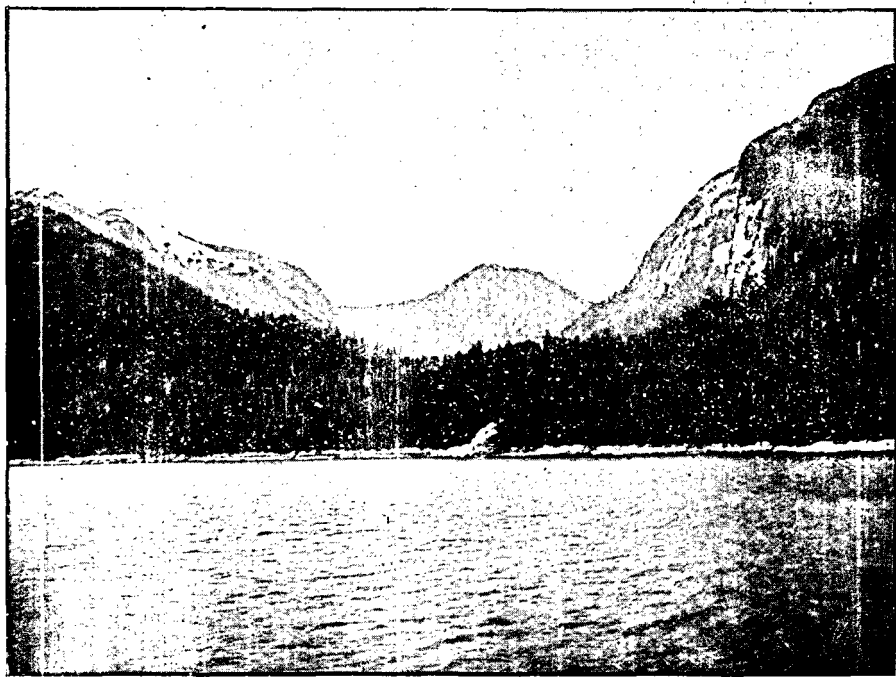


FIG. 2.—A hanging valley. Inside Passage to Alaska. Waterfall of outflowing stream near centre.

because of hardness of the rock, or other reasons, during the process by which the valley bottom, above which they rise, was being worn away. They are abnormal to valleys of stream erosion, but are common and widespread in valleys sculptured by ice.

In non-glaciated regions, under normal conditions, the headwaters of opposing streams are in divides of more or less definite character, though varying markedly under the influence of variation in rock structure, elevation, rainfall, stage of stream development, etc. But in glaciated lands the divides are often very peculiar, and sometimes quite absent. There is every gradation from the sharpened divide to the flattish col, and thence to what I have elsewhere called the "through valley." The

degree of absence of the normal divide is usually directly proportional to the vigour with which the glacier ploughed across it. In extreme cases the divide has been erased and two streams head in a flat, set low between steeply rising hills; or a lake floods the lowered site of the old divide; or perhaps even a single stream now flows from the one valley to the other. The through valley condition, a great aid to travel in glaciated lands, is found in the Alps, in Alaska, in Central New York, and in the Scottish Highlands. It is as characteristic of glaciated lands as are the hanging valley, the steepened slope, and the "canal" valley, and, so far as I am aware, is all but unknown in regions which glaciers have never occupied.

This combination of abnormal topographic features, so common in glaciated lands, is abnormal only when considered in terms of normal stream-valley formation. It becomes perfectly normal when interpreted in terms of glacial erosion. No other rational explanation has ever been proposed, either for the forms themselves or for the fact that they are found only in regions of present or former glaciation. They are so characteristic that they may be classed among the evidences of glaciation. If all the moraines, till, transported boulders, and glacial scratches could be removed from the Scottish Highlands it would still be possible, on the basis of the peculiar topographic features briefly described above, not only to tell that the Highlands had been glaciated, but even to map the region of most intense glaciation. Some day, and that not very distant, a list of the evidences of former glaciation that does not include the peculiar topographic features will be considered far from complete.

APPLICATION TO THE HIGHLANDS.

With this preliminary statement of the phenomena that a student of glacial erosion has reason to expect to find in a glaciated region, let us see to what extent they are illustrated in the region under consideration.¹

In that part of the Loch Lomond valley that lies within the mountains the valley walls are straightened, and show signs of powerful glacial erosion, with distinct evidence of plucking. There are a number of perfect hanging valleys, especially in the upper portion. Of these the one that enters at Inversnaid may be taken as typical. Back from the lake, toward Loch Katrine, the valley is broad with moderate grade—a typical Highland valley. On approaching Loch Lomond its stream suddenly finds itself without a valley and tumbles down the steepened slope of the main trough, giving rise to the fine waterfall at Inversnaid. The contrast between the grades of the upper and lower course of this stream is no greater than that between the broadly open upper valley and the shallow gorge of the lower portion. It is utterly abnormal to stream work, but finds its counterpart in thousands of cases in Alaska and other glaciated lands.

This valley is hanging also at the eastern end where ice erosion

¹ Owing to an accident to my camera, not detected at the time, my photographs illustrating the topographic forms described below were all failures.

along the Loch Katrine trough has lowered the main valley and left this tributary hanging; but here there is no notable waterfall because the eastward drainage is slight in amount. Thus the valley hangs on both ends, a common feature in glaciated regions where slightly divergent ice-currents crossed two different parts of a single valley. I did not tarry here long enough to work out the full history of this valley further than to satisfy myself that it is an ice-dissected remnant of pre-glacial drainage.

Although there are evidences of glacial erosion in the valley of Loch Katrine and Glen Gyle, my view was so obscured by rain that I am not

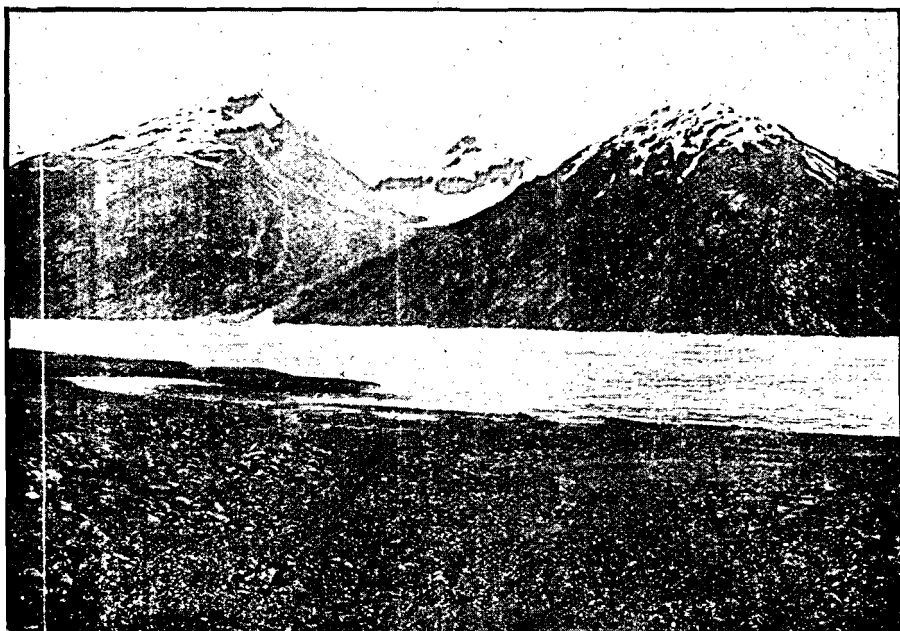


FIG. 3.—A hanging valley in Yakutat Bay, Alaska. Note also the steepened face of the two truncated spurs, on either side of the hanging valley.

able to describe it in detail. The phenomena of glacial erosion seemed, however, to be less clear than elsewhere, as would be expected from the direction of the trough.

From Callander northward to Killin the railway follows a through valley at least as far as the western end of Loch Earn. Along this route a number of hanging lateral valleys are plainly visible.

The valley of Loch Tay is a perfect illustration of an ice-eroded valley with fine truncated spurs, glacially grooved slopes, and a system of immature downhill streams following parallel courses in valleys wholly out of harmony with the drainage of a maturely dissected land surface. Several hanging tributaries enter the main trough at different levels, some of the smaller opening into the valley at an elevation of 500 feet

or more, and the larger at elevations of but one or two hundred feet. There are no bays to the lake because ice erosion has left the lateral valleys too high to be flooded by the lake waters. Consequently, like so many other Scottish lochs, it is long and finger-like. It may, in fact, be classed as a "finger lake." Although glacial erosion has been powerful and effective here, it has not straightened the valley to the condition of a "canal." Parts of the spurs are left and the outline is therefore slightly undulating.

In order to examine one of the hanging valleys more closely a journey was made on foot from Kenmore south-eastward to the divide of the river Quaich. The divide is a broad, fairly flat-bottomed col, evidently lowered and broadened by the passage of ice across it. Descending northward from this col there is an undulating moor in a broad, mature, upland valley. A typical upland stream flows through it with a moderate grade, and the road swings up and down over the moor with a general, but gentle, slope toward the north. When the valley lip is reached, above Kenmore, the grade of the road abruptly increases, and descends the steepened lower slope of the Loch Tay valley by a series of zig-zags, all steep. The change in grade of the road is similar to that of the stream which plunges down the hill-side, in a narrow shallow gorge, with many rapids and falls, clear to the Tay valley. In a mile or less the stream tumbles two hundred feet or more. This description is so typical of the hanging valley condition that it might serve for any one of hundreds of instances in glaciated regions here and elsewhere.

From Kenmore to Kinloch Rannoch I followed the mountain road on foot, past the base of Schiehallion. The col is clearly lowered by glacial erosion, but naturally in an upland region the ice was far less active, and its action less concentrated, than in the valleys. Glacial grooves and roches moutonnées forms in the col, and evidences of plucking and large descending grooves on the slopes of Schiehallion, testify that the ice was not inactive even here.

Loch Rannoch valley has been profoundly modified by glacial erosion. At Kinloch Rannoch there is a perfect example of a truncated spur, and there is another to the east and one to the west of it. In each case the spur has a very steep lower face up to an elevation of three or four hundred feet, and above that the surface has the more gentle slope of the maturely dissected pre-glacial land surface. Between the truncated spur at Kinloch Rannoch, and the one just west of it, there is an excellent hanging valley at high level,—500 to 800 feet in elevation—broadly open at its mouth, and with a stream descending from it, down the steepened slope, in a shallow trench, almost flush with the main valley slope, through which the stream tumbles in a succession of cascades. The tributary valley west of this one is also hanging, but since it is larger, and was evidently itself a highway of glacial flow, its lip is much lower, being but little over 100 feet above the loch. There are also hanging valleys on the south side of Loch Rannoch. No valleys cut the steepened slope or gully the lower face of the truncated spurs. They are too new for that.

From Fort-William to Mallaig, even from the railway, it is plain that

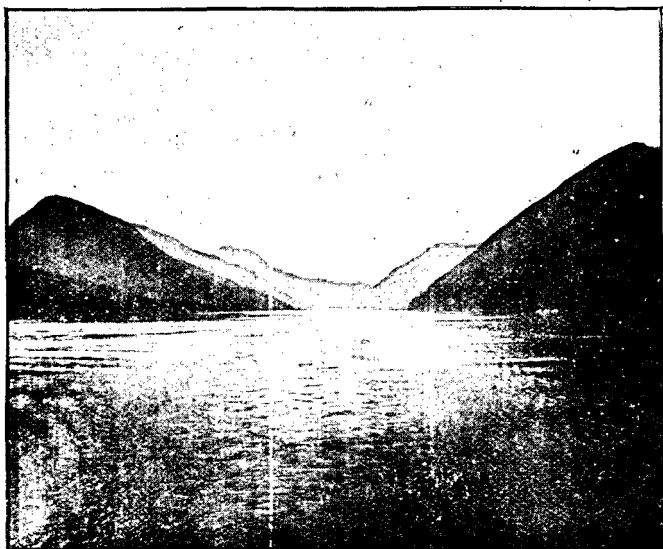


FIG. 4.—Truncated spurs. Inside Passage to Alaska.

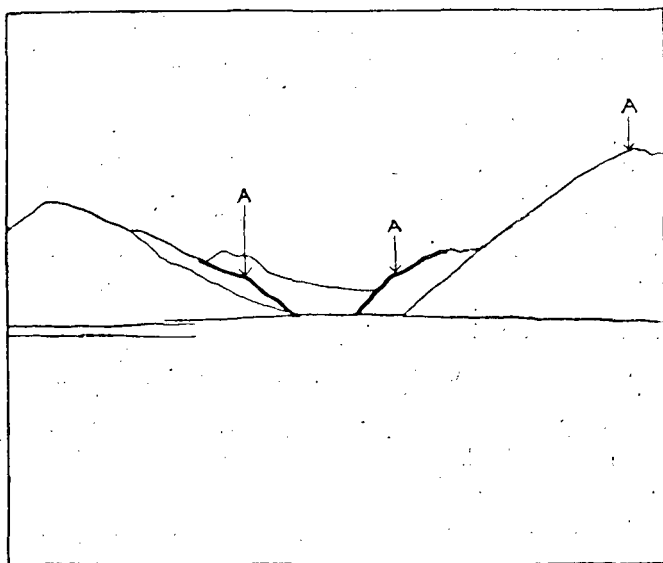


FIG. 5.—A tracing of Fig. 4 to show the change of slope of spurs beneath the letter A—steepened slope below, slightly glaciated slope above the arrows. The outline of the two distant spurs has been inked in order to bring out the change in slope.

there is a series of glaciated valleys; for truncated spurs, steepened

lower valley slopes, with smoothed walls and hanging valleys, are seen every here and there. The larger lateral hanging valleys are themselves broadly U-shaped, indicating that they too were enlarged by glacial erosion, though not sufficiently to lower their bottoms to the depth attained by the main troughs.

A steamboat excursion up Lochs Hourn, Nevis, and Alsh was made during rain, and clear views were rare and local; but enough was seen to convince me of powerful glacial erosion, for all the characteristic topographic features were present. But near the west coast, as at and near Mallaig, where the ice spread out and began to lose that concentration which makes for effective ice erosion, there is clear evidence that the glacier was ineffective. Here there is much irregular rock topography, strikingly contrasting to the rounded surfaces left by vigorous ice scouring; and there is even disintegrated rock in places.

The railway journey from Kyle of Loch Alsh to Dingwall presents further evidence of glacial erosion. There are some small hanging valleys on the sides of Loch Carron, and others up the river Carron valley whose sides are both straight and smooth. The railway slowly rises to the divide, which is flat-bottomed, with a small lake in it, enclosed between steeply rising, smooth-sided valley walls—a stage approaching that of the through valley and made use of for an easy grade across the northern Highlands. Near Luichart Station there are waterfalls where a side-valley enters from Loch Fannich. Below this comes the depression occupied by Loch Luichart, whose depth is probably due to the union of the two glacier currents just above, thus locally increasing the effectiveness of ice erosion. The railway does not descend to the shores of Loch Luichart, but keeps up on the steep slope of the valley until it enters a small hanging tributary, on the north side of which a small stream plunges into the Luichart valley. Through this hanging valley the railway passes to the Garve valley, and here also the lateral is hanging. Thus here, as in the valley between Lochs Lomond and Katrine, there is a dissected remnant of a valley left hanging by glacial erosion on both ends.

Loch Ness is quite like one of the Alaskan "canals." It is remarkably straight, has perfect truncated spurs, numerous hanging valleys, and many waterfalls along its shores. The height of the hanging valleys above the lake level varies greatly and seems to be proportional to the size of the valley, as one would expect. In two cases, both on the north side, the lateral valleys enter the loch at about lake level, forming slight bays. As would be expected, these are the largest tributaries, and hence those in which the ice most nearly equalled that in the main trough in erosive work. Loch Lochy continues the characteristics of Loch Ness.

Whatever the significance of faulting may have been in outlining the main trough of the Caledonian Canal, glacial erosion has certainly put the finishing touches upon it. On the theory of faulting alone it would require great ingenuity to account for the truncated spurs and the difference in level of the hanging tributaries with their broadly U-shape.

In the valleys round about Ben Nevis, notably in Glen Nevis, the

features of glacial erosion are plainly evident, as they are also in the valley of Loch Long.

Thus the evidence, wherever one has reason to expect it, is everywhere the same here in the Scottish Highlands as it is in other glaciated regions. The topography of the crystalline Highlands is in certain significant respects closely like that of the highly folded region of the Alps; of the plateau of Central New York, with the horizontal strata of shale and sandstone; of the crystalline region of parts of Alaska; and of the region of vertical shales and sandstones of other parts of Alaska, as in Yakutat Bay—in fact, in regions of powerful glaciation in general regardless of rock structure. But these topographic features are absent in unglaciated regions, whether we look for them among horizontal strata, as in the plateau of New Mexico, or folded strata, as in the Appalachians of Pennsylvania, or in regions of crystalline rocks, as in the Appalachians of eastern Tennessee, which bear a resemblance to the Highlands of Scotland in other respects. The topographic forms in the Scottish Highlands defy geologic structure; they follow no law except that of persistent association with regions of glaciation and dependence upon the erosive power of glaciers.

The Measure of Erosion.—As I wandered about in the Highlands and saw the hard crystalline rocks deeply grooved, polished, and rounded, I saw what any other student of the subject would have seen—namely, that the glacier had been at work removing rock material from the ledges. The same lesson was taught by the fresh rock surfaces, from which all evidence of pre-glacial disintegration had been removed. Equally convincing was the clear evidence that the glacier was engaged in plucking away larger fragments from the ledges, presented by the hackly surface of the ledges themselves as well as by the vast numbers of boulders deposited all over the Highlands. No one questions this much erosion, but some hesitate to take the next step, just as some long hesitated to believe that rivers could perform the work which every one now assigns to them.

If, however, this measure of erosion is granted, what more is needed than that same element which early geologists hesitated to give to rivers for their work—namely, time? Yes, there is one other element, that of concentration of energy, which rivers also need. A river spread out over the country would be but a poor agent of erosion; but confined along a narrow line it becomes a powerful agent, sawing deeply into the hardest of rocks. Give glaciers time, and even though they grind away but an inch a year, the sum total of their work will become noteworthy, and especially where their currents are directed along narrow valleys and fed from numerous side-valleys.

The argument against glacial erosion has been mainly based upon the supposed ineffectiveness of ice; and this in turn is based largely upon a study of such weak, inefficient agents as the dwindling glaciers of the Alps. Who would think of studying the upper Thames at a period of low water to learn how a Colorado canyon was cut? Yet this comparison is warranted, for the Alpine glaciers are no more to be thought of as in the same category with the profound ice-streams that wound

their way through the Highland valleys than are the Thames and Colorado River. Let the observer go to the huge glaciers of Greenland or Alaska if he would learn what ice is capable of doing.

But I would not rest the argument for glacial erosion in the Scottish Highlands even on this. The topography is the main proof of it, and not merely by comparison with other regions, but even by comparison of different parts of the Highland region itself. Wherever in the Highlands the ice spread out, and hence became ineffective in erosion, one sees the normal conditions of a maturely dissected land surface—normal divides, accordant tributaries, irregularities due to subaerial denudation, and even disintegrated rock. Wherever one enters a trough along which he has reason to expect that ice currents moved vigorously, he finds topographic forms normal to ice work and common in and confined to regions where glaciers have been, but utterly out of harmony with the known results of river denudation—steepened valley walls, truncated spurs, hanging valleys, erased tributaries, lowered cols, and through valleys. To the person who has convinced himself of the significance of these features, everything falls into harmonious relationship. It seems fair, therefore, to ask what other explanation can be suggested that is equally satisfactory? And further, what other argument against it can be urged except that of the preconceived notion that ice cannot erode much—the same dogma that Lyell fought so effectively as applied to the work of rivers?

This paper, as applied to the Highland region, is confessedly based upon a very brief study, though the phenomena are so clear and distinct, and so like those studied much more fully in other regions, that even "he who runs may read." Naturally, under the circumstances, no attempt was made to follow out details, for it was the basal principles only that were sought. I will not, therefore, attempt to say how the various ice currents flowed, nor how much they removed from the valleys. It was clear to me, however, that the ice streams were directed by the local topography along many divergent courses, probably during the stage of most extensive glaciation as well as in the dwindling stages of local valley glaciation. It was equally clear that practically all the good-sized valleys suffered profound glacial scouring and were thereby greatly modified. The measure of glacial erosion in many instances is hundreds of feet, and in places perhaps as much as a thousand feet, thus being comparable to the erosive activity of the Alaskan glaciers and the continental glaciers in the Finger Lake region of Central New York.

The acceptance of the glacial erosion explanation of the topographic features of the Scottish Highlands, described above, leads of necessity to the conclusion that many of the characteristic features of the region are ice-shaped. In large part the peculiarly charming scenery is the product of glacial erosion, coupled with other glacial action. Of course the main mountain forms are of independent origin, though modified in detail by ice scouring. The upland topography is also largely of pre-glacial subaerial origin, though again modified in detail by ice work. But the larger valleys depart widely from their pre-glacial condition.

Doubtless all of them had existence in some form before the coming of the ice; but all the valleys through which ice moved freely have been widened and deepened by ice scouring, different ones to different depths according to the resistance of the rock in which they lie and to the power of the ice current that flowed through them. Some have been eroded so far that their beds now lie beneath the sea, and are occupied by marine lochs.¹ Others have been differentially eroded, forming rock basins in which fresh-water lochs exist, often held up in part, or even mainly, by morainic dams. Still others have been connected with neighbouring valleys by the lowering of divides over which ice currents freely flowed. Altogether, therefore, the drainage has been greatly modified by the ice work; and not least of the effects is the formation of innumerable waterfalls, mainly in association with the hanging valleys. Such are some of the conclusions that the belief in powerful glacial erosion demands—not the making of a new topography, but the shaping and modification of a pre existing land already irregular.

The geographic consequences of this glacial shaping and modification are many and important. Without the lowered cols, the through valleys, and the lochs, we may well believe that the history of the Highlands would have been quite different. Even now not easily accessible, the region would then have been far less so; for from its geologic structure and physiographic history we may fairly infer that its topography would be not unlike the crystalline mountain region of western Carolina and eastern Tennessee in the United States, a region surrounded by a well-settled country, but out of touch with it all, and still preserving customs of a century ago—a barrier to travel, and with no natural highways either into or across it.

After two weeks in the Scottish Highlands, I spent a delightful week in the English Lake District under the guidance of Dr. Marr and Professor Garwood. There the topographic forms found in the Scottish Highlands were repeated, often in most perfect form, as a student of glacial erosion would naturally expect to be the case. Having made this excursion under the guidance of one who is himself making a special study of the physiography of the region, I shall not attempt to describe the phenomena observed; but I cannot resist the statement that the topography of the English Lake District eloquently testifies to the powerful erosive work of the glacial currents that flowed through its valleys. Where, indeed, is there a region of powerful glaciation that does not? Or where is there an unglaciated region that duplicates the abnormal (abnormal to stream erosion) topographic features of the Scottish Highlands and the English Lake District?

¹ It is not intended to deny subsidence as an element in their formation.